Year: 2019

Accuracy of Computer-Guided Template-Based Implant Surgery: A Computed Tomography-Based Clinical Follow-Up Study

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Abstract: OBJECTIVE The aim of this clinical study was to analyze the accuracy of computer-guided implant surgery. MATERIALS AND METHODS Assisted by computed tomography (CT)-based planning software and navigational templates, 16 patients successfully received 26 dental implants. Each implant parameter (a-d) was calculated based on superimposed preoperative and postoperative cone beam CT scans: (a) deviation at entry point; (b) deviation at apex; (c) angular deviation; and (d) depth deviation. RESULTS Mean central deviation at implant entry point and apex was 0.91 mm (standard error [SE] = 0.11 mm; 95% confidence interval [CI]: 0.69-1.13) and 1.22 mm (SE = 0.11 mm; 95% CI: 0.99-1.45), respectively. Mean angulation deviation was 4.11 degrees (SE = 0.52 degrees; 95% CI: 3.04-5.17) and the average depth deviation was 0.65 mm (SE = 0.11 mm; 95% CI: 0.42-0.87). For the total number of implants placed, the maximum error was 2.34 mm at entry point, 2.71 mm at apex, 9.44 degrees in angular deviation, and 2.00 mm in depth deviation. CONCLUSION Great accuracy was reached even in advanced cases with prior bone augmentation and complex traumas. This leads to the conclusion that particularly in advanced cases, computer-guided implantation can be beneficial.

DOI: https://doi.org/10.1097/ID.0000000000000936

Originally published at:
Schelbert, Tobias; Gander, Thomas; Blumer, Michael; Jung, Ronald; Rücker, Martin; Rostetter, Claudio (2019). Accuracy of Computer-Guided Template-Based Implant Surgery: A Computed Tomography-Based Clinical Follow-Up Study. Implant Dentistry, 28(6):556-563.
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Accuracy of Computer-Guided Template-Based Implant Surgery: A Computed Tomography–Based Clinical Follow-Up Study

Tobias Schelbert, DMD,* Thomas Gander, MD, DMD,† Michael Blumer, MD, DMD,† Ronald Jung, DMD,‡ Martin Rücker, MD, DMD,§ and Claudio Rostetter, MD, DMD¶

Objective: *The aim of this clinical study was to analyze the accuracy of computer-guided implant surgery.*

Materials and Methods: *Assisted by computed tomography (CT)-based planning software and navigational templates, 16 patients successfully received 26 dental implants. Each implant parameter (a–d) was calculated based on superimposed preoperative and postoperative cone beam CT scans: (a) deviation at entry point; (b) deviation at apex; (c) angular deviation; and (d) depth deviation.*

Results: *Mean central deviation at implant entry point and apex was 0.91 mm (standard error [SE] = 0.11 mm; 95% confidence interval [CI]: 0.69–1.13) and 1.22 mm (SE = 0.11 mm; 95% CI: 0.99–1.45), respectively. Mean angulation deviation was 4.11 degrees (SE = 0.52 degrees; 95% CI: 3.04–5.17) and the average depth deviation was 0.65 mm (SE = 0.11 mm; 95% CI: 0.42–0.87). For the total number of implants placed, the maximum error was 2.34 mm at entry point, 2.71 mm at apex, 9.44 degrees in angular deviation, and 2.00 mm in depth deviation.*

Conclusion: *Great accuracy was reached even in advanced cases with prior bone augmentation and complex traumas. This leads to the conclusion that particularly in advanced cases, computer-guided implantation can be beneficial. (Implant Dent 2019;28:556–563)*

Key Words: template-guided, bone augmentation, computer-aided, cone beam computed tomography

Since the original 2-stage surgical protocol was described, prosthetic rehabilitation with dental implants gradually became a routine procedure with high implant survival rates and reliable predictability. The number of specialists and general practitioners placing implants with varying expertise is rapidly increasing.[1–3]

To achieve high success rates, detailed clinical and radiological preoperative diagnostics are crucial. The optimal implant position depends on obtaining chewing function and satisfactory esthetics of missing teeth by prosthetic-driven implant placement.[4] Neither conventional radiographic templates nor the 2-dimensional images of dental panoramic tomography provide sufficient information about the varying mucosal thickness or the buccolingual width of the jawbones.[5] This lack of information usually constrains the surgeon to choose the final implant position after the raised flap exposes the bone and possibly exhibits unexpected challenges, such as insufficient bone width or bone defects.[6]

Lower costs, reduced radiation, and increased availability support the growing popularity of computed tomography (CT), including dental cone beam computed tomography (CBCT), for implant position planning.[7]

Special 3D software, generating an exact virtual 3-dimensional model of available bone quantity, quality, and anatomical structures and pathologies, makes CT the most precise and comprehensive radiologic technique for dental implant planning.[8,9] Congruency between CBCT and multiple detector computed tomography has been shown

*Doctoral Student, Clinic of Cranio-Maxillo-Facial and Oral Surgery, University Hospital Zurich, Zurich, Switzerland.
†Senior Physician, Clinic of Cranio-Maxillo-Facial and Oral Surgery, University Hospital Zurich, Zurich, Switzerland.
‡Head of Division of Implantology and Vice Chairman of Clinic of Fixed and Removable Prosthodontics and Dental Material Science, Center of Dental Medicine, University of Zurich, Zurich, Switzerland.
§Professor and Head of Clinic of Cranio-Maxillo-Facial and Oral Surgery, University Hospital Zurich, Zurich, Switzerland.
¶Assistant Physician, Clinic of Cranio-Maxillo-Facial and Oral Surgery, University Hospital Zurich, Zurich, Switzerland.

Reprint requests and correspondence to: Claudio Rostetter, MD, DMD, Clinic of Cranio-Maxillo-Facial and Oral Surgery, University Hospital Zurich, Frauenklinikstrasse 24, Zurich, CH 8091, Switzerland, Phone: +41 44 255 11 11, Fax: + 41 44 255 89 89, E-mail: claudio@rostetter.net

ISSN 1056-6163/19/02806-556
Implant Dentistry
Volume 28 • Number 6

DOI: 10.1097/ID.0000000000000936

in several publications, whereas CBCT seems to be sufficient for 3-dimensional implant planning.[10] Superimposition of the prosthetic wax up incorporates prosthetic and anatomical aspects into the 3D model and allows the practitioner to virtually place an implant in the most favorable position.

To transfer the virtual planning into the clinical situation, computer-guided implantation uses a static surgical template to provide guidance as a position marker and to secure the drill in each direction[11,12] (Fig. 1).

Surgical templates can be fabricated manually by a dental technician or using computer-aided design and computer-aided manufacturing (CAD/CAM), approaching a fully digital workflow. Examining accuracy of implant position, both described templates significantly enhance precision compared with freehand placements.[8,11] The type of tissue supporting the template has an influence on the accuracy of implant placement. Tooth- and mucosa-supported templates seem to be more accurate than bone-supported templates.[6,13]

Precise preoperative implant planning with computer-guided implantation allows for more beneficial implant positioning, particularly supporting implant esthetic in the anterior maxilla and mandible including the premolars and combined with flapless surgery, the patient benefits from a shorter surgical time and reduction of patient morbidity.[14] Despite the mentioned advantages, the clinical benefits from computer-guided implantation are a matter of controversy.[15]

Operating close to vital structures, such as vessels and nerves, accuracy determines both safety and effectiveness of computer-guided implantation.[16]

Accuracy, clinical advantages, survival rates, and possible complications in computer-guided implantation have been widely assessed and several systematic reviews were published in the past years.[8,11,13,17–19] However, the majority of studies were conducted *in vitro*, whereas *in vivo* studies and studies on cadavers show less accuracy in implant placement.[19] Therefore, additional *in vivo* studies are necessary

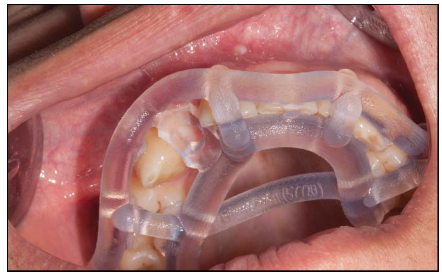

Fig. 1. Photograph of an *in situ* drill template produced with CAD/CAM technology. A metallic drill guide is placed into the cylindrical hole in the gap from the missing upper right lateral incisive tooth. The design of the tooth-supported template allows checking for a tight fit and proper stability.

to evaluate reliable safety margins in implant planning for practitioners.

The aim of this clinical study was to determine the accuracy of 3-dimensionally planned, template-guided dental implants based on routine follow-up CBCT scans due to underlying pathologies caused by the initial trauma.

Our hypothesis is advanced cases with inadequate bone offer a backward planed surgical-template support harvest and precise application of bone graft material in 2-stage bone augmentations. Consequently, less augmentation material is required. Less invasive, locoregional bone augmentation becomes sufficient in most cases. The same surgical template is used to place the implant precisely in the augmented bone region.

MATERIALS AND METHODS

Data Acquisition

All patients included in this study signed an informed consent for scientific use of data. The study was conducted in full accordance with ethical principles, including the World Medical Association Declaration of Helsinki (version, 2013). In addition, the ethics committee of Zürich approved the study protocol (KEK-ZH-No. 2016-00028). There were no sources of external funding for this project. There were no conflicts of interest.

All patients who from 2015 until 2017 received a computer-guided dental implant at the Department of Cranio-Maxillo-Facial and Oral Surgery, University Hospital of Zurich, as well as a follow-up CBCT due to pathologies caused by the initial trauma, were included for this study. Inclusion criteria involved the 3-dimensional treatment planning based on a preoperative CBCT scan and the application of a stereolithographic surgical template while implant surgery. The patient had to be excluded if the implant was not fully displayed in the follow-up CBCT.

For every patient, the same CBCT unit KaVo 3D eXam (KaVo, Biberach, Germany) with an amorphous silicon flat panel detector (20 × 25 cm) was used. The exposed volume was set at a height of 102 mm. The voxel size in all axes was 0.25 mm, and the thickness of the reconstruction increment was 0.4 mm. The scan was set at a high-frequency constant potential of 120 kV (peak), and the occlusal plane for each patient was set parallel to the floor by using a chin rest.

Data were saved in Digital Imaging and Communications in Medicine (DICOM) format. Furthermore, clinicians performed an intraoral scan (Cerec omnicam; Sirona Dental Systems, Wals, Germany). The dental models were exported as standard triangle language (STL) format files.

3-Dimensional Implant Planning and Template Fabrication

Online surgical implant planning software (Swissmeda online implant planning [SMOP]; Swissmeda, Zürich, Switzerland) processed the acquired data and allowed for registration of the digitalized dental models (STL file) onto the CBCT scans (DICOM) (Fig. 2). Well-experienced clinicians specified the most favorable implant position, regarding prosthetic, anatomical, and chewing load aspects. A surgical template was designed and the STL data set, provided by the implant planning software, transferred to a dental laboratory. A rapid prototyping machine (Objet Eden 260V; Stratasys, MN; Layer thickness: 0.016 mm) fabricated an individual surgical template (Objet Med 610; Stratasys) using the principle of stereolithography.

Surgical Protocol

All the surgeries were performed by the same and well-experienced

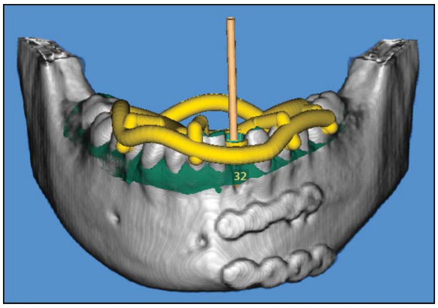

Fig. 2. Screenshot from the virtual implant planning and template design in SMOP. The preoperative CBCT scan (gray) from the lower jaw is superimposed with the intraoral scan (green) of the mandibular teeth. On these scans, the implant position for the missing lower lateral incisive and the drill template design is planned digitally (yellow).

clinicians at the Department for Cranio-Maxillo-Facial and Oral Surgery of the University Hospital of Zurich. Surgeries were executed under local anesthesia with or without general anesthesia, using conventional flap technique. Where necessary, a 2-stage bone augmentation with locoregional or autologous bone was implemented previous to implantation, taking the prefabricated surgical template as guidance.

Implant surgery procedure was performed with the template *in situ* and according to the protocol of the inserted implant. Most surgical templates were both-sided tooth-supported (cap situation, 16 implants), a few were one-sided tooth-supported (free-end situation, 4 implants), and one template was only mucosa-supported (edentulous, 2 implants). Twenty-four Astra Tech implants (OsseoSpeed TX; Dentsply Implants, Mannheim, Germany) and 2 Straumann implants (Standard Plus; Straumann, Basel, Switzerland) were placed. No immediate loading with provisional restorations was executed.

Accuracy Assessment

The STL data file from the planned situation was fused with the postoperative CBCT scan using craniomaxillofacial planning software iPlan Net 3.0 (Brainlab Inc., Feldkirchen, Germany). Superimposition of preoperative and postoperative models based on surface registration and aligning of anatomical and tooth structures was performed to reduce merging errors to a minimum (Fig. 3). For each planned and placed implant, all three-dimensional coordination points (x/y/z) of entry point and apex were measured along the implants' axis. The entry point refers to the center of the prosthetic connection of the implant, whereas the apex refers to the tip of the implant. Using mathematical vectors, the true 3-dimensional deviation between planned and placed implants were calculated for these previously defined parameters: (a) deviation at entry point; (b) deviation at apex; (c) angular deviation; and (d) depth deviation relative to the planned implant axis (Fig. 4).

Statistical Analysis

Descriptive analysis of quantitative data were performed and described with mean values, standard errors (SE), and 95% confidence intervals (95% CIs). Apical and coronal deviations were categorized into 3 groups, as described by Valente et al[12]: 0 to 1 mm (slight, clinically negligible deviation); 1 to 2 mm (moderate, probably clinically irrelevant); and >2 mm (potentially clinically relevant). Boxplots and histograms were used for illustration. Difference in means between subgroups, divided based on surgical variables, were compared with 2-sample *t* tests. The following surgical variables were tested as categorical factors: jaw (maxilla/mandible), number of implants placed with same template (1/2), and bone augmentation previous to implantation (yes/no). All analyses were performed at a significance level of 0.05, using statistical software (R-project statistical software version 3.2.3; R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

From October 2015 until July 2017, 16 patients aged between 24 and 81 years met the inclusion criteria of our study. The most frequent cause of trauma in the observed patients were various kind of falls (7), followed by bicycle crashes (3) and, astoundingly, plane crashes (2), which occurred as often as epileptic seizures (2). Mandibular collum and corpus fractures were united with accompanying injuries such as mild to severe soft tissue traumas or hematomas, the most often general injuries. Before implantation, a 2-stage bone augmentation was performed for 11 of the total 26 implant sides. Retromolar mandibular grafts (4) and crista zygomatico-alveolaris grafts (3) were transplanted, as well as in single cases an anterior mandibular graft, a locoregional cortical bone graft, and a sinus

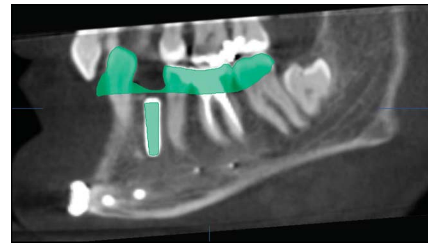

Fig. 3. Screenshot from Brainlab showing the sagittal plane of a superimposed STL (green) and CBCT (gray) scan to examine the deviation between the planned (green) and achieved (grey) implant position. For precision, the deviation was then calculated with the exact 3-dimensional coordinates from apex and entry point from every planned and placed implant.

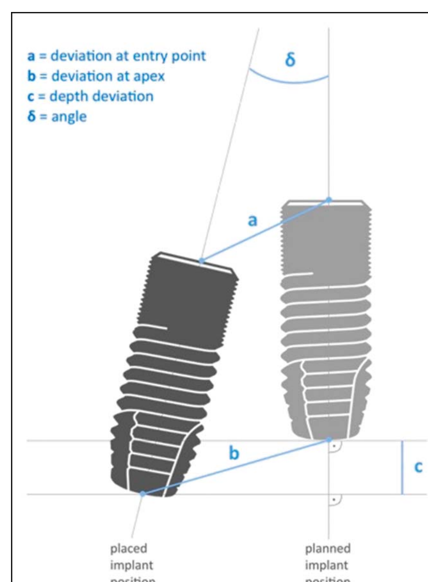

Fig. 4. The illustration shows how the deviation (blue) at entry point (**A**), at apex (**B**), in depth (**C**), and in angulation (δ) was examined between planned (light gray) and achieved (dark gray) position for every implant. The center of the prosthetic connection of the implant (entry point) and the tip of the implant (apex) was determined with three-dimensional coordinates.

floor elevation was applied. Table 1 gives a short overview of the 16 observed patients (Table 1).

Deviations from surgically achieved and virtually planned implant positions were calculated and compiled for each implant, and statistical analysis was performed. The results are listed in Tables 2 and 3.

The average discrepancy between planned and achieved surgical implant placement at the entry point was 0.91 mm (SE = 0.11 mm; 95% CI: 0.69–1.13). The corresponding data at the apex were 1.22 mm (SE = 0.11 mm; 95% CI: 0.99–1.45). Average angulation discrepancy was 4.11 degrees (SE = 0.52 degrees; 95% CI: 3.04–5.17). The average depth deviation was 0.65 mm (SE = 0.11 mm; 95% CI: 0.42–0.87). The minimum and maximum errors between planned and placed implants were also determined. For the total number of implants, the maximum error was 2.34 mm at the entry point, 2.71 mm at the apex, 9.44 degrees in angular deviation, and 2.00 mm in depth deviation.

Categorized as previously described by Valente et al,[12] only one implant showed a potentially clinical relevant deviation greater than 2 mm at the entry point. Ten implants had moderate deviations between 1 and 2 mm, and 15 implants presented less than 1-mm deviation.

At the apex, 2 implants showed deviations greater than 2 mm, 13 implants had deviations between 1 and 2 mm, and 11 implants had less than 1-mm deviation (Fig. 5).

Regarding only patients who received single implants, the mean deviation errors were 0.86 mm (SE = 0.18 mm; 95% CI: 0.46–1.27) at the implant entry point, 1.23 mm (SE = 0.19 mm; 95% CI: 0.79–1.66) at the apex, 0.63 mm (SE = 0.18 mm; 95% CI: 0.21–1.05) depth deviation, and 3.35 degrees (SE = 0.70 degrees; 95% CI: 1.76–4.94) angular deviation.

Table 1. Characteristics of the Observed Patients

Cause of Trauma	Age at Presentation (y)	Date	Gender	General Injuries	Dental Injuries	Implants Placed	Applied Bone Augmentation
Fell on chin	67	October 2015	M	Collum mandibulae fracture (right)	Vertical fracture (44)	44	Retromolar mandibular graft
Fell on face	64	January 2016	F	Soft tissue trauma	Vertical fracture (36)	36	Retromolar mandibular graft
Fell on chin	81	January 2016	F	Hematoma	Root fracture (11; 12)	11; 12	Crista zygomatico-alveolaris graft
Fell with ice skates	24	March 2016	F	Collum mandibulae fracture (right)	Vertical fracture (15)	15	Sinus floor elevation
Bicycle crash	58	March 2016	F	Mild soft tissue trauma	Luxation implant (33)	33; 44	None
Plane crash	45	May 2016	M	Mandibular fracture	Mixed fractures (24; 25; 36)	24; 25; 36	Crista zygomatico-alveolaris graft
Fell in bath	44	June 2016	M	Mild soft tissue trauma	Implant fracture (12)	12	Crista zygomatico-alveolaris graft
Epileptic seizure	57	June 2016	F	Corpus mandibulae fracture (left)	Avulsion (44)	44	Retromolar mandibular graft
Blunt punch to face	28	July 2016	M	Jaw subluxation	Root fracture (11)	11	None
Bicycle crash	30	August 2016	F	Polytrauma with mandibulae fracture	Avulsion (25; 34)	25; 34	Retromolar manibular graft
Bicycle crash	58	August 2016	F	Soft tissue trauma	Luxation (12)	12	None
Epileptic seizure	41	October 2016	F	Haematoma	Root fracture and avulsion (32; 42)	32; 42	Anterior mandibular graft
Fell under influence of alcohol	29	April 2017	M	Hematoma	Root fracture (11; 22)	11; 22	None
Fell on escalator	24	Mai 2017	M	Mild soft tissue trauma	Root fracture (31)	31	None
Bicycle crash	31	Mai 2017	M	Soft tissue trauma	Root fracture (11; 21)	11; 21	None
Plane crash	33	July 2017	M	Multilocal mandibular fracture (left)	Vertical fracture (14; 15; 24; 25; 45)	14; 15; 24; 25; 45	Locoregional cortical bone graft

The table gives a short overview with the most important characteristics for each of the 16 observed patients including cause of trauma, dental injury, implants placed, and applied bone augmentations.

Table 2. Table With Mean Deviation and SE of Deviation for the Total of all Implants (Overall) and Divided by Type of Jaw, Numbers of Implants Placed, and Bone Augmentation Applied (Subgroups)

		(In mm)						(In Degrees)	
		Entry Point		Apex		Depth		Angle	
	No.	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Overall	26	0.91	0.11	1.22	0.11	0.65	0.11	4.11	0.52
Subgroups									
Maxilla	11	0.47	0.07	0.88	0.12	0.32	0.07	4.95	0.86
Mandible	15	1.23	0.13	1.47	0.15	0.89	0.15	3.49	0.61
Single	10	0.86	0.18	1.23	0.19	0.63	0.18	3.35	0.70
Double	16	0.94	0.14	1.21	0.15	0.66	0.14	4.58	0.71
Bone sufficient	15	1.06	0.16	1.38	0.16	0.80	0.16	4.81	0.71
Bone augmented	11	0.70	0.11	0.99	0.12	0.44	0.11	3.14	0.68

The deviations are given between planned and achieved implant position at entry point (mm), apex (mm), in depth (mm), and in angulation (degrees).

For patients receiving 2 implants with the same template, the means were 0.94 mm (SE = 0.14 mm; 95% CI: 0.65–1.23) deviation at the entry point, 1.21 mm (SE = 0.15 mm; 95% CI: 0.90–1.52) deviation at the apex, 0.66 mm (SE = 0.14 mm; 95% CI: 0.36–0.96) depth deviation, and 4.58 degrees (SE = 0.71 degrees; 95% CI: 3.07–6.09) angular deviation.

Multiple implants placed with the same template showed higher mean deviations in all analyzed parameters compared to single placed implants; however, these differences were not statistically significant.

The mean deviation errors for implants placed in the maxilla were 1.23 mm at the entry point, 1.47 mm at the apex, 0.89 mm in depth, and 3.49 degrees in angulation, whereas the mean deviation errors for implants placed in the mandible were 0.47 mm at the entry point, 0.88 mm at the apex, 0.32 mm in depth, and 4.95 degrees in angulation.

Implants placed in the maxilla showed a significantly higher deviation at the entry point, the apex, and in depth than implants placed in the mandible.

A statistically significant error between implants placed with (11) and without (15) prior autologous bone augmentation was found only for implant depth deviation, showing less depth deviation in implants with autologous bone augmentation.

DISCUSSION

The present *in vivo* prospective study demonstrates the accuracy of computer-aided template-guided implant placement in partially and fully edentulous trauma patients. The study indicates that the results might be depending on various crucial factors, such as the location of implant placement (maxilla/mandible) and previous additional autologous bone augmentation.

The technology of computer-guided implant placement offers clinicians with better possibilities in preoperative virtual implant planning and guidance during implant surgery; however, new technologies are prone to limitations and risks and it is important to determine their accuracy and reliability.

Accuracy is defined as the deviation in location or angulation between the actually placed and the virtually planned implant.[9] Several reviews of scientific literature have been performed to survey the accuracy of computer-guided implantation with stereolithographic surgical templates.[8,9,11,15,17,20–23]

D'haese et al[17] calculated a mean deviation of 1.04 mm (95% CI: 0.20–1.45) at the implant entry point and 1.64 mm (95% CI: 0.95–2.99) at the apex. Mean angular deviation calculated was 3.54 degrees (95% CI: 0.17–7.90). Schneider et al[11] reported deviations of 1.07 mm (95% CI: 0.76–1.22) at the implant entry point, 1.63 mm (95% CI: 1.26–2.00) at the apex, 0.43 mm (95% CI: 0.12–0.74) vertical, and between 5 and 6 degrees in angulation. When examining *in vivo* studies, a meta-analysis of Van Assche et al[22] showed a mean deviation error of 1.0 mm (95% CI: 0.7–1.3) at the implant entry point, 1.4 mm (95% CI: 1.1–1.7) at the apex, and 4.2 degrees (95% CI: 3.6–5.0) in angulation. The present *in vivo* study showed similar accuracy with 0.91-mm deviation at the implant entry point, 1.22-mm deviation at the implant apex, 0.65-mm deviation in implant depth, and 4.11 degrees deviation in implant angulation.

Potential errors leading to deviation of the implant position can be accumulated through a sequence of diagnostic and therapeutic events. Valente et al[12] described that single errors during image acquisition and data processing on average are less than 0.5 mm and errors in surgical template production are typically around 0.2 mm for templates fabricated with

Table 3. Table With Minimal and Maximal Deviations for the Total of All Implants (Overall) and Divided by Type of Jaw, Numbers of Implants Placed, and Bone Augmentation Applied (Subgroups)

		(In mm)						(In Degrees)	
		Entry Point		Apex		Depth		Angle	
	No.	Min	Max	Min	Max	Min	Max	Min	Max
Overall	26	0.20	2.34	0.23	2.71	0.03	2.00	0.42	9.44
Subgroups									
Maxilla	11	0.20	0.92	0.23	1.58	0.05	0.84	0.91	9.44
Mandible	15	0.50	2.34	0.55	2.71	0.03	2.00	0.42	8.65
Single	10	0.20	1.82	0.23	2.37	0.06	1.73	0.91	7.2
Double	16	0.29	2.34	0.55	2.71	0.03	2.00	0.42	9.44
Bone sufficient	15	0.20	2.34	0.57	2.71	1.2	9.44	0.05	2.00
Bone augmented	11	0.21	1.39	0.23	1.57	0.03	1.36	0.42	8.65

The minimal and maximal deviations are given between planned and achieved implant position at entry point (mm), apex (mm), in depth (mm), and in angulation (degrees).

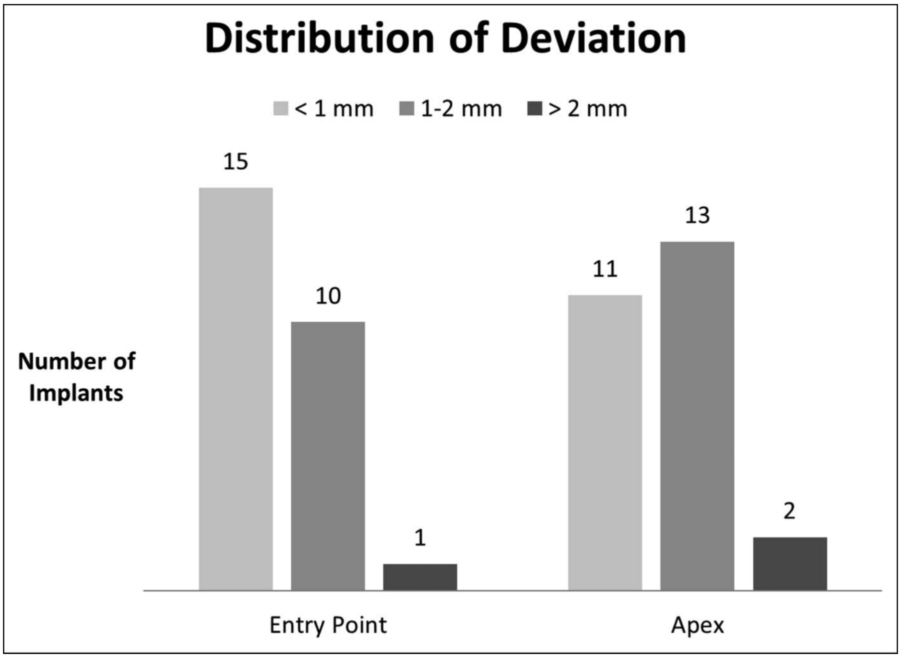

Fig. 5. Distribution of deviation divided by the classification by Valente et al. The figure shows how many implants had deviations less than 1 mm (light gray), between 1 and 2 mm (gray), and above 2 mm (dark gray) at entry point (left) and apex (right).

stereolithography. Inadequate template position, template movement during drilling, tolerance of the burr-cylinder cap, and omission of the template because of insufficient mouth opening of the patient are mentioned as additional errors that can be accumulated and thereby may result in a loss of accuracy.[12]

There is no consensus about the accuracy needed in computer-guided implantation, and categorization of data about precision is susceptible for criticism. The categorization of Valente et al[12] characterizes deviations exceeding 2 mm as clinically relevant, considering the generally recommended safety margin of 2 mm around vital structures.[24] In his study, one fourth of the implants showed clinically relevant deviations greater than 2 mm, pointing to the need for further investigations.[12] In this study, only 2 implants (7.5%) showed deviation errors greater than 2 mm at entry point or apex. Over one half (61.5%) of implants showed deviations between 1 and 2 mm, and slightly less than one third (31%) of all implants showed deviations less than 1 mm. In preoperative virtual implant planning determination of safety margins considering the worst-case-scenario, where all deviations summarize in the same direction, potentially causing damage to vital anatomical structures, is crucial.

In a previous study, Widmann et al[8] showed that implants placed with the same template are not independent from each other and errors may cumulate. If multiple implants are placed with the same template, they are linked in various stages of implant planning and placement. These findings are in line with this study, higher mean deviations in all analyzed parameters for multiple placed implants per template, compared with single placed implants per template, were detected too.

In our study, implants in the maxilla showed a significantly higher deviation than mandibular implants at the entry point (1.23 vs 0.47 mm), the apex (1.47 vs 0.88 mm), and in depth (0.89 vs 0.32 mm). These findings are in agreement with other studies, reporting that the maxilla is more susceptible to transfer inaccuracies than the compact mandibular bone.[6,12] By contrast, the meta-analysis by Van Assche et al[22] did not show any significant difference between maxillary and mandibular implants.

Our hypothesis is that with backward planned templates, the needed bone dimension is determined before surgery and minimizes the amount of transplanted graft material needed. These findings are in line with Fortin et al[25] who elucidated that bone augmentation procedures may be avoided or reduced by optimizing implant positioning in accessible bone. Malo et al[26] found in their study that backward planned implantation allows for dental rehabilitation in edentulous jaw with a minimal bone augmentation. Bone scraper from locoregional bone or grafts from the corresponding quadrant was sufficient in all our cases. This computer-assisted procedure reduced the morbidity to a minimum, and no impairment in accuracy was found in this study.

There was no differentiation by the type of implant (Astra Tech/ Straumann) used in our study. These findings are limited by the small sample size. In a multicenter *in vivo* study by Valente et al,[12] the type of implant used exhibited no significant differences in accuracy of computer-guided implantation.

Equivalently, there was no differentiation by template support (tooth [15]/mucosa [1]). Accomplishment of sufficient template stability on mucosa seems to be more difficult than on teeth because the degree of freedom in fully edentulous patients is higher than in partially edentulous patients. Ozan et al[6] found that tooth-supported surgical templates were more accurate than mucosa-supported surgical templates, which is in contrast with Valente et al.[12]

One aspect to be taken into account is the restricted sample size of this study. Due to its limiting inclusion criteria, only a few patients qualified for the current study. None of the patients were exposed to study-induced supplementary radiation, which makes the study unique. Furthermore, to the best of our knowledge, this is the first clinical study to examine the accuracy of computer-guided implantation in patients requiring 2-stage bone augmentation techniques in combination with comparing the accuracy between the implants placed with and without prior bone augmentation.

The optimal implant position regarding anatomical and prosthetic circumstances in virtual planning is a matter of debate and may differ significantly between studies; however, the esthetic advantages of virtual implant planning, particularly in the anterior and premolar maxilla and mandible, should be emphasized.

This study includes advanced cases, for example, patients with multiple trauma, which may be more difficult to plan virtually and perform surgically. Therefore, accuracy may be fundamentally compromised in an advanced case.[27] Performing template-guided surgery in advanced cases is promising and should be further examined on larger trials.

CONCLUSION

The present *in vivo* study shows a high accuracy between the virtually planned and surgically achieved position of template-guided implantation with autologous bone augmentation in complex trauma cases, which leads to the conclusion to implant exclusively with virtually planned methods in advanced cases.

DISCLOSURE

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

APPROVAL

The study was conducted in full accordance with ethical principles, including the World Medical Association Declaration of Helsinki (version, 2013). In addition, the ethics committee of Zürich approved the study protocol (KEK-ZH-No. 2016-00028).

ROLES/CONTRIBUTIONS BY AUTHORS

T. Schelbert: study conception and design, acquisition of data, analysis and interpretation of data, drafting of manuscript, and critical revision. T. Gander: study conception and design, analysis and interpretation of data, and critical revision. M. Blumer: analysis and interpretation of data, drafting of manuscript, and critical revision. R. Jung: analysis and interpretation of data, drafting of manuscript, and critical revision. M. Rücker: study conception and design, drafting of manuscript, and critical revision. C. Rostetter: study conception and design, acquisition of data, analysis and interpretation of data, drafting of manuscript, and critical revision.

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